In: 11th Seminar on Environmental Protection „Environment and Health“. 20.-23. November 2000, Thessaloniki, Greece, 155-166.

ATMOSPHERIC CONDITIONS AND HUMAN THERMAL COMFORT IN URBAN AREAS

A. Matzarakis and H. Mayer

Meteorological Institute, University of Freiburg

Werderring 10, D-79085 Freiburg, Germany

Abstract

Climate and air quality must be taken into account in urban and regional planning at regional level in a manner which is relevant to human health and well being. In view of the combined effects of atmospheric conditions on man, thermal, air quality and actinic factors are particularly important in preventive planning.

The thermal factors comprise such meteorological elements as air temperature, air humidity, wind velocity, short and longwave radiation, which have a thermo-physiological effect on man outdoors and indoors; the significance to health is associated with the close linking of thermoregulation and circulatory regulation.

The most important meteorological parameter affecting the energy balance of humans during sunny conditions is the mean radiant temperature. It considers the uniform temperature of a surrounding surface giving off blackbody radiation which results in the same energy gain of a human body given the prevailing radiation fluxes. The latter usually vary considerably under open space conditions.

The model „*RayMan*“ for the calculation of shortwave and longwave radiation fluxes on the human body is presented. The model estimates the radiation fluxes and the effects of clouds on shortwave radiation fluxes. The model which takes complex urban structures into account is suitable for use and planning purposes in urban areas. The final output of the model is, however, the calculated mean radiant temperature which is required in the energy balance model for humans and thus for the assessment of urban bioclimate and such thermal indices as Predicted Mean Vote (PMV), Physiologically Equivalent Temperature (PET) and Standard Effective Temperature (SET*). The model is developed based on the German VDI-Guidelines 3789, Part II: Environmental Meteorology, Interactions between Atmosphere and Surfaces; Calculation of the short- and longwave radiation and VDI-3787: Environmental Meteorology, Methods for the human biometeorological evaluation of climate and air quality for the urban and regional planning at regional level. Part I: Climate.

In: 11th Seminar on Environmental Protection „Environment and Health". 20.-23. November 2000, Thessaloniki, Greece, 155-166.

1. Introduction

Humans have been aware that weather and climate affect health and well being. Hippocrates, 2.500 years ago, wrote about regional differences of climate and their relationship to states of health. Folklore anywhere is rich in belief about the effect of seasons and weather fluctuations on physical and mental health. Fevers vary seasonally; so do mood and various psychological disorders; aches and pains in joints flare up in winter; and heatwaves can debilitate and kill (WMO, 1999).

The apparent increased instability of weather patterns in many parts of the world in recent years, new insights into cyclical phenomena such as El Nino, and the evidence suggesting that the global climate is beginning to change in response to greenhouse gas emissions, have focused new attention on health consequences of the climate (WMO, 1999). Another point is that most people live in cities and spend the major part of their time there.

2. Methods

2.1 Atmospheric environment

Cause and effect relations between the atmospheric environment and human health or human comfort can be analyzed by a human biometeorological classification (JENDRITZKY, 1990; MATZARAKIS and MAYER, 1996; VDI, 1998) that distinguishes (Fig. 1):

- the thermal complex
- the air pollution complex
- the actinic complex
- and biotropy.

The thermal complex comprises the meteorological factors air temperature, air humidity and wind velocity, and also contains the short- and longwave radiation that thermo-physiologically affects humans in indoor and outdoor climate. This complex is relevant to human health because of a close relationship between the thermoregulatory mechanism and the circulatory system.

The air pollution complex includes those solid, liguid and gaseous natural and anthopogenic compounds that cause adverse health effects in humans, indoors as well as outdoors. The relevance of air quality conditions to human health depends on the emission sources and the transmission conditions (dispersion, dilution, possible chemical reactions, wash out and rain out of air pollutants). These factors are determined by atmospheric layers (grade of turbulence), wind, precipitation, and possibly humidity and solar radiation.

In: 11th Seminar on Environmental Protection „Environment and Health“. 20.-23. November 2000, Thessaloniki, Greece, 155-166.

The actinic complex comprises the visible and ultraviolet range of the solar radiation that shows – apart from mere thermal effects – direct biological effects.

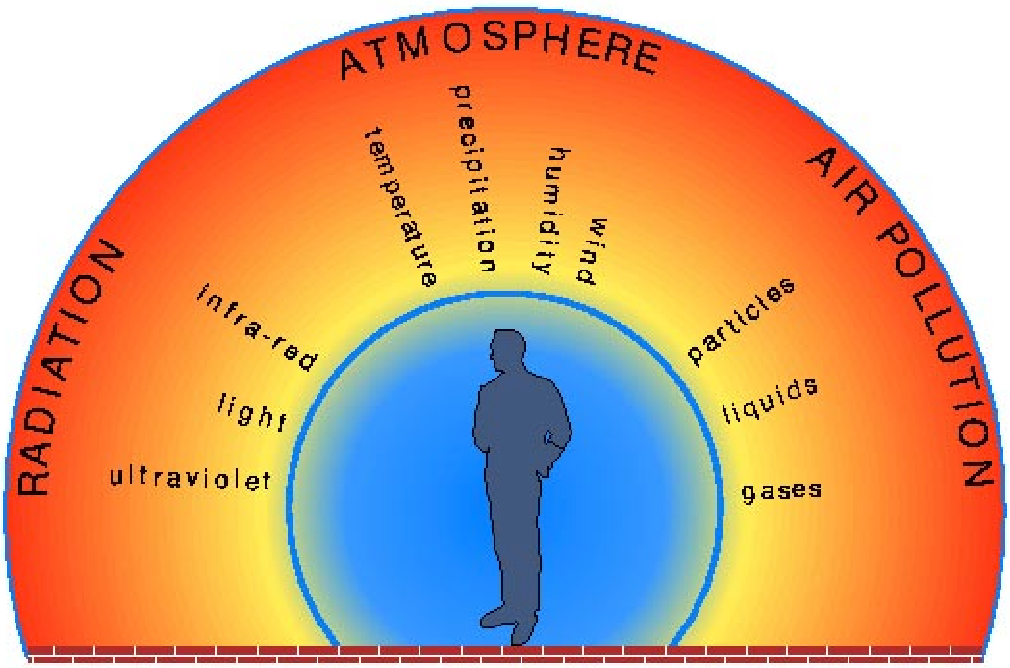

Figure 1: Atmospheric environment and human (WMO, 1999).

Biotropy deals with the biological effects of the weather. There are three possible reactions of the human organism to the weather: body reactions, slight and intense meteorosensitivity.
The fact that air pollution can seriously affect human health has long been acknowledged and resulted in numerous limit, guide and threshold values of air pollutants. Is importance is not least due to the fact that air pollution occurs all year – though for different pollutants at different levels and that hardly any individual protection can be taken against it.
The thermal complex, however, is often understimated, especially in the Central European climate region, although long-term data statistics show increased mortality rates at extreme thermal conditions (heat or cold stress) (JENDRITZKY, 1992).

2.2 Assessment of the thermal complex

Human biometerological studies have already been carried out for some time. In the past thermal indices were frequently used to estimate the thermal environment. These indices were based on single or composite meteorological parameters, such as wet bulb temperature or equivalent temperature.

In the seventies of the 20th century, some scientists began to use physiologically relevant indices that were derived from the human energy balance for the assessment of the thermal complex (HÖPPE, 1993). A model for the human energy balance is MEMI (Munich Energy Balance for Individuals), which uses the assessment index PET (Physiologically Equivalent Temperature). This model is described in VDI-Guideline 3787, Part 2 "Methods for the Human-Biometeorological Assessment of Climate and Air Hygiene for Urban and Regional Planning" (VDI, 1998).

Table 1 : Threshold values of the thermal indexes Predicted Mean Vote PMV and Physiologically Equivalent Temperature PET for different grades of thermal sensivity of human beings and physiologic stress on human beings, internal heat production: 80 W, heat transfer resistance of the clothing: 0.9 clo (according to MATZARAKIS and MAYER, 1996)

PMV	PET	Thermal Sensivity	Grade of Physiologic Stress
		very cold	extreme cold stress
-3.5	4 °C	-----------------------------	--
		cold	strong cold stress
-2.5	8 °C	-----------------------------	--
		cool	moderate cold stress
-1.5	13 °C	-----------------------------	--
		slightly cool	slight cold stress
-0.5	18 °C	-----------------------------	--
		comfortable	no thermal stress
0.5	23 °C	-----------------------------	--
		slightly warm	slight heat stress
1.5	29 °C	-----------------------------	--
		warm	moderate heat stress
2.5	35 °C	-----------------------------	--
		hot	strong heat stress
3.5	41 °C	-----------------------------	--
		very hot	extreme heat stress

The following meteorological parameters were taken into account in MEMI:

- air temperature
- vapour pressure
- wind velocity

- mean radiation temperature

Body parameters used in MEMI are:

- human activity and body heat production
- heat transfer resistance of clothing.

Like the frequently used PMV index (Predicted mean Vote), PET makes it possible to access thermo-physiologically (see table 1) the thermal conditions of surrounding indoor and outdoor air, as point calculations or in form of maps (MATZARAKIS, 1995).

2.3 Importance of radiation fluxes in human-biometeorological studies

For the estimation of thermal indices it is easy to obtain meteorological data like air temperature, air humidity and wind speed. The mean radiant temperature T_{mrt} is the most important meteorological input parameter for obtaining the human energy balance during summer weather conditions. Therefore, T_{mrt} has the strongest influence on thermophysiological significant indices like PET (Physiologically Equivalent Temperature) or PMV (Predicted Mean Vote) which are derived from models for the human energy balance (MAYER, 1993).

T_{mrt} is defined as the uniform temperature of a surrounding surface giving of blackbody radiation ($\varepsilon = 1$), which results in the same radiation energy gain of a human body as the prevailing radiation fluxes. The latter are usually very varied under open space conditions. The procedure for the measurement of T_{mrt} is very complex and needs much time (HÖPPE, 1992; MATZARAKIS and MAYER, 1998).

In literature, methods to estimate radiation fluxes based on parameters including air temperature, air humidity, degree of cloud cover, air transparency and time of the day of the year are recommended. But the albedo of the surrounding surfaces and their solid angle proportions must also be specified. Additionally other factors like the geometrical properties of buildings, vegetation, etc. have to be known and to be take into consideration.

The model *RayMan* which is presented here is well suited for the calculation of the radiation fluxes especially within urban structures, because it considers various complex horizons (MATZARAKIS et al., 1999).

Working with *RayMan* (Fig. 2) at a PC, an input window for urban structures (buildings, deciduous and coniferous trees) is provided. The possibility of free drawing and output of the horizon (natural or artificial) are included for the estimation of sky view factors. Also possible is the input of fish-eye-photographs for the calculation of sky view factors. The amount of clouds covering the sky can be included by free drawing while their impact on the radiation fluxes can be estimated.

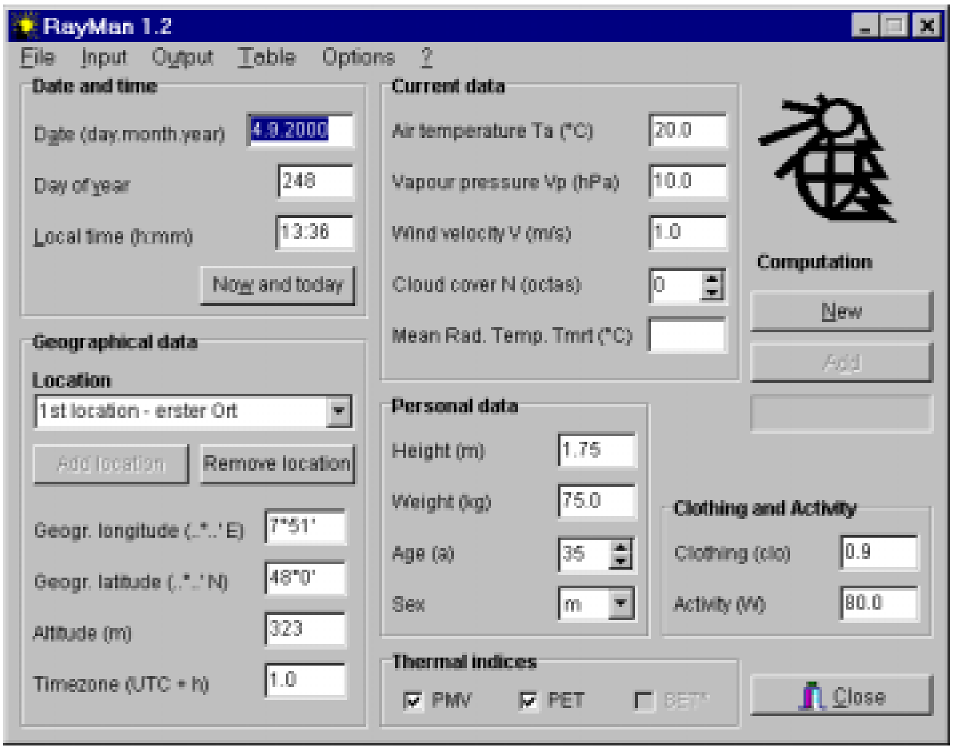

Figure 2: Input window of *RayMan* 1.2 and the relevant values for the calculation of mean radiant temperature and thermal indices.

In the field of urban climatology and humanbiometeorology the most important question is, if an object of interest is shaded or not. Hence, in the presented model shading by urban and natural obstacles is included.

Horizon information need to be known to obtain sun paths. Calculation of hourly, daily and monthly averages of sunshine duration, short wave and long wave radiation fluxes with and without topography and obstacles in urban structures can be carried out with *RayMan*. These can be with meteorological input of manual data or files. The output is given in form of graphs and text data.

The final output of the model is, however, the calculated mean radiant temperature which is required in the energy balance model for humans, and thus for the assessment of urban bioclimate and such thermal indices as Predicted Mean Vote (PMV), Physiologically Equivalent Temperature (PET) and Standard Effective Temperature (SET*). The model is developed based on the German VDI-Guidelines 3789, Part II (VDI, 1994) and 3787 Part I (VDI, 1998).

3. Results
3.1 General example

The PET thermal index, which can be calculated by *RayMan*, is suitable for the evaluation of the thermal environment not only in summer, but also throughout the whole year. As an example of such an application in a Mediterranean climate, Fig. 3 shows mean, highest and lowest PET values at 12 UTC per day at Thessaloniki (at Mikra Airport) in Greece in the period 1980 - 1989. This kind of illustration provides good information on the variability of PET on each individual day of the year within the investigation period. The results of Fig. 3 show that different grades of cold stress (PET < 18 °C) occurr mostly from October to April. Mean PET values over 30 °C, indicating at least moderate heat stress, can be found from June to September, which is a period of 4 months. On some hot summer days from May to September, PET at 12 UTC was over 40 °C, representing a pronounced thermal stress level in Thessaloniki.

3.2 Examples in urban areas

On the other hand the urban structures in urban areas are very complex and the variability of the meteorological values are very high (MATZARAKIS and MAYER, 1998). As a typical example, Fig. 4 and 5 compare results from *RayMan* and measurements, were carried out on July 19th, 1999 in Freiburg, south-west Germany. The latter refers to measurement site 4 (MP 4) marked out as one of the measurement sites for human-biometeorological evaluations of urban structures. The MP 4 site is situated under a tree crown on a small green area in the northern area of the city. The selected day July 19th, 1999 was a beautiful summer day, that recorded cumulus cloud cover about midday. The sky-view factor amounted to 0.12 on the basis of an appraised fish-eye photograph in the opposite MP6 in a near by street canyon with sky view factor of 0.58.

The results presented in Fig. 4 and 5 show that the T_s and T_{mrt} derived from *RayMan* are satisfactory. The agreement is relatively good in the morning, while in the following hours greater differences, up to 5.1 °C in T_s and up to 6.8 °C in T_{mrt}, appear. This could be due to emerging cumulus cloud cover on one hand, an effect that still has to be improved in *RayMan*. On the other hand, the difference could also be due to the effect of the extremely complex structures at this measurement site, which is not completely represented in the present version of *RayMan*. It is, however interesting that the simulation of T_s and T_{mrt} by *RayMan* on radiation-days agree considerably with measured values.

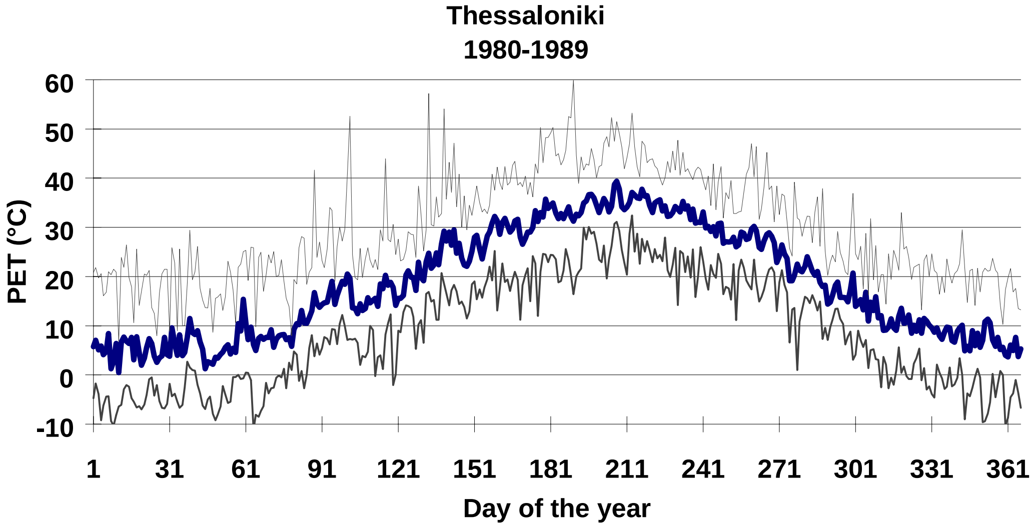

Figure 3: Mean, highest and lowest values per day of Physiologically Equivalent temperature (PET) at 12 UTC at Thessaloniki, for the years 1980-1989.

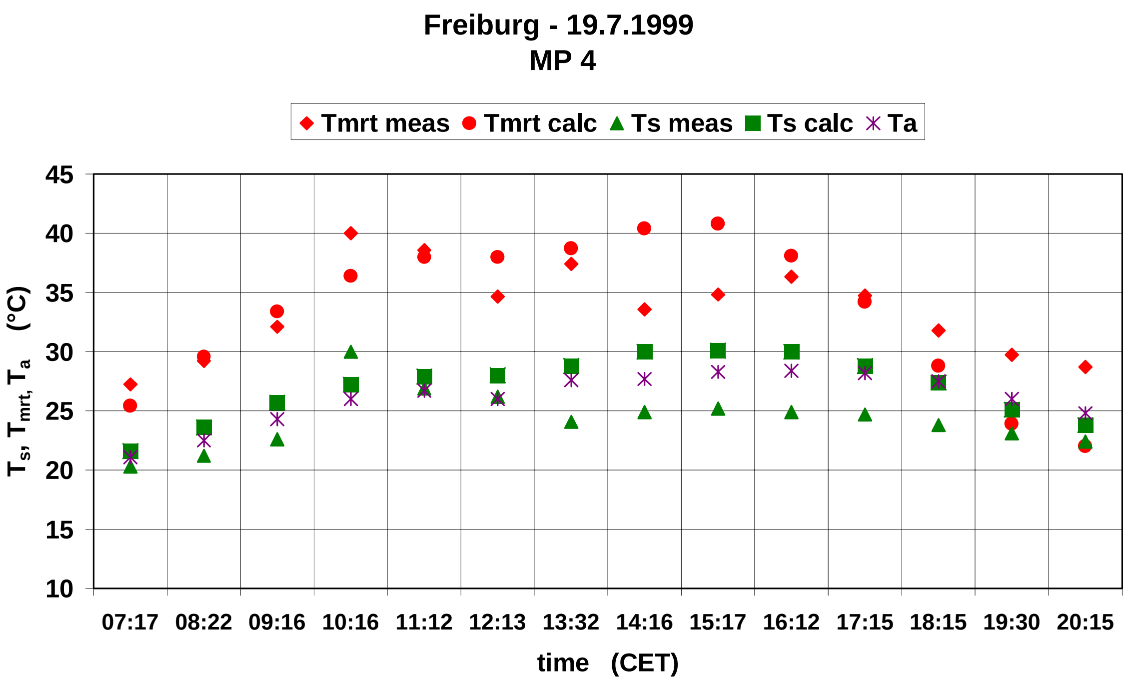

Figure 4: Output of measured mean radiant temperature $T_{mrt\ meas}$, computed mean radiation temperature $T_{mrt\ calc}$, measured surface temperature $T_{s\ meas}$, calculated $T_{s\ calc}$ and air temperature T_a for July 19th,1999 for MP4.

In: 11th Seminar on Environmental Protection „Environment and Health". 20.-23. November 2000, Thessaloniki, Greece, 155-166.

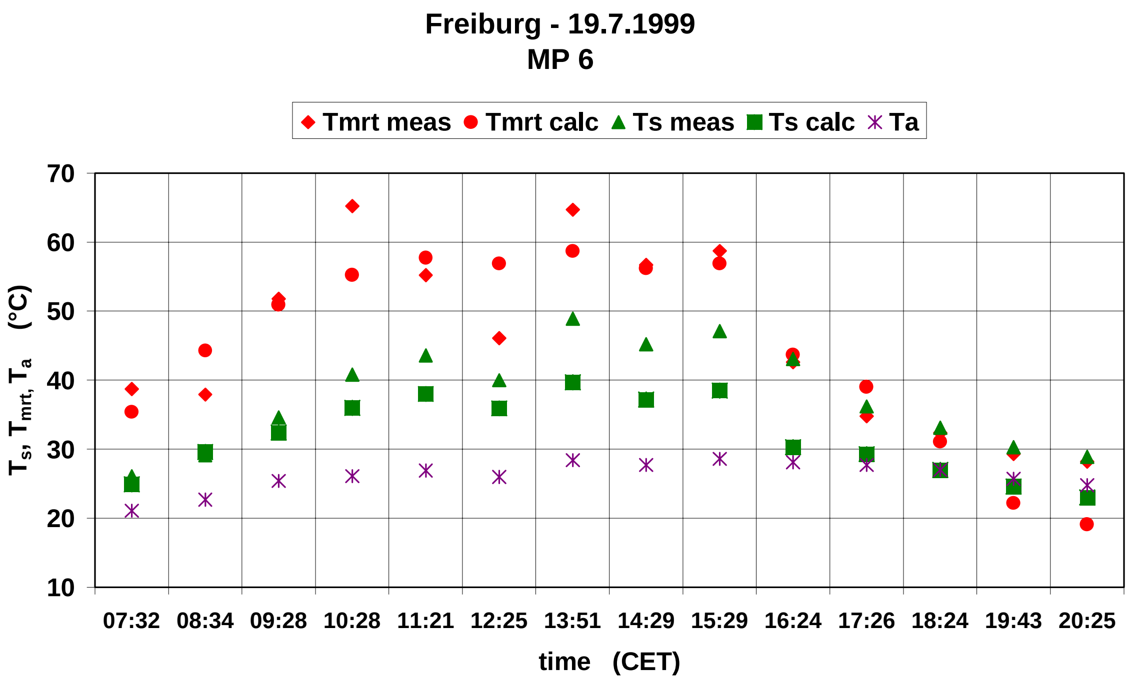

Figure 5: Output of measured mean radiant temperature $T_{mrt\ meas}$, computed mean radiation temperature $T_{mrt\ calc}$, masured surface temperature $T_{s\ meas}$, calculated $T_{s\ calc}$ and air temperature T_a for July 19th,1999 for for MP6.

Table 2 : Mean and maximum differences between the site street canyon north and the site below some tree crowns for air temperature, T_a, global radiation G, longwave radiation A from the upper hemisphere, longwave radiation E from the lower hemisphere, mean radiant temperature T_{mrt} and Physiologically Equivalent Temperature PET.

	Site 'street canyon, north' - *Site 'below some tree crowns'*			
	Mean		Max	
T_a	0.4 °C	*1.5 %*	1.7 °C	*6.1 %*
G	323 W/m^2	*94.9 %*	935 W/m^2	*99.0 %*
A	-47 W/m^2	*-10.8 %*	-59 W/m^2	*-13.3 %*
E	66 W/m^2	*12.6 %*	121 W/m^2	*20.5 %*
T_{mrt}	14.7 °C	*32.0 %*	32.4 °C	*49.7 %*
PET	9.0 °C	*26.5 %*	19.8 °C	*41.2 %*

In table 2 are listed the mean and maximum differences between the site street canyon north and the site below some tree crowns for air temperature, T_a, global radiation G, longwave radiation A from the upper hemisphere, longwave radiation E from the lower hemisphere, mean radiant temperature T_{mrt} and Physiologically Equivalent Temperature PET. The results in table 2 shows that there are existing differences which are expresses the quantitative effects of trees in urban areas and explain the relevance of trees for the urban climate and human beings.

Conclusion

Results of humanbiometerological analysis of different spaces are of interest because of their possible application in:

- urban and landscape planning (regarding investigation of impacts of big constructional projects),
- tourism (for the selection of holiday or the duration of holidays),
- giving advice concerning the location of residential areas,
- climate change and relation to human biometeorology and
- climate and health (for the analysis of thermal stress situations).

For the evaluation of the thermal component of urban and regional climate precise and high resolution radiation data of the whole surrounding is necessary. This data can be either measured or calculated using a radiation model. *RayMan* is able to do the latter and is available for general use under (http://www.mif.uni-freiburg.de/rayman).

References

HÖPPE, P., 1992: Ein neues Verfahren zur Be-stimmung der mittleren Strahlungstemperatur im Freien. Wetter und Leben **44**, 147-151.

HÖPPE, P., 1993: Heat balance modelling. Experientia **49**, 741-746.

JENDRITZKY, G., MENZ H., SCHIRMER H., SCHMIDT-KESSEN, W. (1990) Methodik zur raumbezogenen Bewertung der thermischen Komponente im Bioklima des Menschen (Fortgeschriebenes Klima-Michel-Modell). Beitr. Akad. Raumforsch. Landesplan. No. 114.

JENDRITZKY, G., 1992: Wirkungen von Wetter und Klima auf die Gesundheit des Menschen.

Handbuch der Umweltmedizin VI-3. (Hrsg.: H. E. Wichmann, H.-W. Schlipköter, G. Fülgraff), ecomed, Landsberg, 1-14.

MATZARAKIS, A., 1995: Human-biometeorologische Bewertung des Klimas von Griechenland. Dissertation. Aristotelian University of Thessaloniki, Thessaloniki.

MATZARAKIS, A.; MAYER, H., 1991: The extreme heat wave in Athens in July 1987 from the point of view of human biometeorology. Atmospheric Environment **25B**, 203-211.

MATZARAKIS, A.; MAYER, H., 1996: Another Kind of Environmental Stress: Thermal Stress. NEWSLETTERS No. 18, 7-10. WHO Colloborating Centre for Air Quality Management and Air Pollution Control

MATZARAKIS, A., MAYER, H., 1998: Investigations of urban climate's thermal component in Freiburg, Germany. Preprints Second Urban Environment Symposium - 13th Conference on Biometeorology and Aerobiology. November 2.-6. 1998, Albuquergue, USA, American Meteorological Society. 140-143.

MATZARAKIS, A., RUTZ, F., MAYER, H., 1999: Estimation and calculation of the mean radiant temperature within urban areas. Proceedings of the 15th International Congress of Biometeorology & International Conference on Urban Climatology. (Ed.) R.J. de Dear and J. C. Potter. ICB9.2, 1-6.

MAYER, H., 1993: Urban bioclimatology. Experientia **49**, 957-963.

VDI, 1994. VDI 3789, Part 2: Environmental Meteorology, Interactions between Atmosphere and Surfaces; Calculation of the short- and long wave radiation. Beuth, Berlin, 52 pp.

VDI, 1998. VDI 3787, Part I: Environmental Meteorology, Methods for the human biometeorological evaluation of climate and air quality for the urban and regional planning at regional level. Part I: Climate. Beuth, Berlin, 29 pp.

WMO, 1999: Climate and human health. World climate News 14, 3-5.

Authors address:

Dr. Andreas Matzarakis or Prof. Dr. Helmut Mayer, Meteorological Institute, University of Freiburg, Werderring 10, D-70985 Freiburg, Germany, phone: +49-761-2036921, fax: +49-761-2036922, email: matzarak@uni-freiburg.de or hmayer@uni-freiburg.de, Internet: http://www.mif.uni-freiburg.de